

PROJECT MERCURY
A DESCRIPTION OF THE ASTRONAUT'S TASK
IN PROJECT MERCURY

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SUMMARY

The basic functions of Project Mercury Astronauts are reviewed. Included are discussions of the contributions of the Astronauts in such mission tasks as systems management, sequence monitoring, attitude control, navigation, and communications. In addition, the nonflight assignments are briefly reviewed.

ASTRONAUT'S ROLE IN MERCURY SYSTEM

The Mercury vehicle is designed as an automatic system which, if all components work correctly, can complete an unmanned flight. This fact has sometimes obscured the important role that the Astronaut will play in the operation of the system during manned flights. The extent to which the Astronaut has control over the Mercury vehicle operation is frequently misunderstood. At first view, the lack of control over the booster at launch and the lack of a horizontal landing capability has sometimes led to the erroneous conclusion that the Astronaut was a passive-observer passenger aboard the Mercury vehicle. This attitude overlooks the fact that the Astronaut has complete control over attitude in orbit and on reentry and that he has control over secondary power in orbit. It overlooks the more basic consideration that attitude control, which is the central problem in piloting aircraft, may be less significant in space flight. Experience in Project Mercury tends to indicate that the pilot's role in backing up his onboard systems and taking over in the event of malfunction is a very demanding and time-consuming task. It is not the purpose of this paper to defend man's role in space-flight systems. It is, however, basic to an understanding of the Astronaut's task in Mercury to recognize that the job demands levels of skill similar to those required in flying high-performance aircraft. The Astronaut's task from a pilot's point of view was the subject of a paper presented by one of the Mercury Astronauts, Capt. D. K. Slayton, at the Society of Experimental Test Pilots (Oct. 9, 1959).

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The integration of the Astronaut in the Mercury system provides added reliability and flexibility of flight. His role can be illustrated by the schematic sequence diagram for the retrograde portion of the mission given in figure 1. (Note that the prefix "retro" is adopted herein as a simplification for terms associated with the retrograde maneuver.) Above the dotted line are the components which must function automatically in order successfully to carry out the retrograde maneuver during unmanned flights. In some cases, provision is made for redundant systems; for example, either the clock may be reset to start retrofire or a direct command signal is available to start this sequence. In other cases, however, only one system exists for accomplishing a given task. Thus, achieving retroattitude is dependent upon correct function of the automatic stabilization and control system (ASCS). If this system does not function, retroattitude cannot be achieved and the mission will be compromised.

When man is added, a number of redundant systems come into play. Retroattitude may now be achieved not only by the automatic control system, but also by three manual control systems using fly-by-wire, rate command, or proportional manual control. Thus, whereas, without man a single method of achieving a mission requirement existed, with the insertion of the man into the system, three new methods or a total of four partially or fully redundant systems are available. Other examples of the multiple redundancies provided by the crew can be seen on the diagram. For example, in determining time for retrofiring, the Astronaut has four communication channels with the ground to receive time information. Should communications fail, he has two external reference systems for determining retrotime. He can achieve retrofire in the following ways: setting the clock, starting the retrosequence, and directly initiating retrofire. Retrofire is only one example of the additional redundancies and, therefore, of the reliability achieved through the action of the Astronaut. At nearly every point in the sequence, the Astronaut has override and backup capability. Except for guidance control over the booster, the Astronaut has control over all aspects of the mission.

CREW SPACE AND INSTRUMENT PANEL

As background to a discussion of the pilot's tasks during the flight, a brief review of the general layout of the crew space and the instrument panel will be helpful. Figure 2 gives a sketch of the Astronaut in the Mercury capsule. In his full pressure suit, he sits in a molded couch. Approximately 27 inches in front of his face is the Mercury instrument panel. Just above the panel is a small window giving a view out of the capsule which is similar to the normal aircraft wind

screen view, with the exception, of course, that the Astronaut is looking backward rather than forward along his flight path. Centered in the instrument panel is the display from the periscope which looks out the base of the capsule and gives a nadir view of the earth directly below the capsule. To the Astronaut's left is his survival pack; to his right, storage facilities for water, food, and waste; slightly forward of this is the emergency egress hatch. Capsule lighting is provided by fluorescent tubes to the side and above the Astronaut's head. On the left side of the main instrument panel is a large fuse panel with 23 fuses. In this area also is the storage position for the emergency flashlight and a hooked stick used to extend the Astronaut's reach, should pressurization interfere with his mobility to the extent where he could not reach one of the rings or buttons on the panel.

Next a view is given of the instrument panel itself (fig. 3). This panel is seen to embody some traditional aircraft concepts and some novel display systems. As in conventional aircraft, the flight instruments occupy the center of the panel. The colored panels divide the instruments into functional units: attitude control, launch and reentry sequencing, environmental control system, electrical system, communications, and the enunciator panel. The panel contains 35 indicators, 38 lights, 57 electrical and 34 mechanical controls. In addition to these displays, the Astronaut has two external viewing systems; the window and the periscope. Finally, the Astronaut must make use of miscellaneous cues such as sound, vibration, acceleration, heat, and pressure changes which provide indications of system function.

This panel is the result of considerable study by the McDonnell Aircraft Corporation, the Minneapolis-Honeywell Company, and the Astronauts themselves. The problems of operating the vehicle in the full pressure suit have been considered by placing as many of the controls as possible to the sides and along the bottom of the panel. Rings and T-handles which permit firm gripping with the suit gloves have been used on mechanical controls. They are rotated slightly off the vertical in order to minimize the possibility of inadvertent operation of an adjacent control. As with all instrument panels, design compromises were required. Thus, all mechanical controls were required to be on the left-hand panel for structural reasons. This interfered, in some cases, with the placing of controls and displays in logical system groups.

THE ASTRONAUT'S TASKS

The Astronaut performs eight basic functions during the Mercury flight:

(1) The primary flight task of the Astronaut can be labeled "systems management." This includes monitoring the environmental control system, electrical system, attitude control system and communications system, and in the event of a malfunction, determining the nature of the problem, its effect on the mission, and taking over manual control where necessary.

(2) A second task, "programing" or "sequence monitoring," is, in a sense, a type of systems management but has a number of unique factors which make it of special interest. This activity involves the monitoring of the critical events of the launch and reentry of the Mercury vehicle. These events such as separation from the booster, retrofire, deployment of parachutes, and such, are critical to a successful mission and involve rapid and accurate reactions to malfunction cues.

(3) Control of vehicle attitude is an important Astronaut task and involves a number of unique problems not encountered in standard aircraft.

(4) A fourth task is navigation. The Astronaut must know his position at all times, and this knowledge involves both ground reference and astronavigation.

(5) An important sub-task is communications. Communications play a more significant part in the space mission than in standard aircraft operations. Through communications, the Astronaut receives important navigation, fuel management, and trajectory data while keeping the ground informed of flight progress.

(6) A sixth important flight task is to make research observations. A basic goal of the Mercury project is to evaluate man's capability in space. The Astronaut has an important role in this research and in the evaluation of data available to him from his unique position in space.

(7) To accomplish these six in-flight tasks, the Astronaut must be able to keep himself in good condition under the physical stresses which he will meet. He develops and applies special skills for meeting acceleration, weightlessness, heat, and other phenomena.

(8) Finally, each flight must begin with a period of ground launch preparation and countdown and must end with a period of waiting for pickup on the surface of the sea. The Astronaut has many important responsibilities in these launch and recovery operations.

Systems Management

The first major area of the Astronaut's activity during the flight is systems management. In order for the Mercury mission to be successfully accomplished, the four major Mercury systems (attitude control, environmental control, electrical system, and communications system) must function correctly throughout the mission. In the event of failure of one of these systems, the pilot may activate secondary or backup systems. In addition to taking action to back up these automatic systems, he must determine the effect of the failure and take proper action to modify the mission in the event it is no longer possible to accomplish the original objectives. Systems management may become one of the most important areas of man's activities in space flight. Because of the requirement for prolonged periods of flight without access to ground support, there will be a special emphasis on maintaining the systems functions. This requirement exists only partially in Mercury. The total Mercury flight profile of 3 orbits or $4\frac{1}{2}$ hours is well within the flight time periods of current modern-day aircraft. However, even in the most dire emergency, the Astronaut cannot leave the vehicle for at least 20 minutes. There can be no provision for bailout. Thus, Mercury represents an intermediate step between aircraft and longer life space vehicles in the requirement for basic system reliability. The basic concepts of man's integration into the Mercury capsule to provide additional system reliability have been outlined in the investigations of Edward R. Jones at McDonnell Aircraft Corporation and reported in a paper presented at a meeting of the American Rocket Society, Sept. 1959.

Figure 4 gives a schematic analysis of the Astronaut's sub-tasks in systems management. The first step in the Astronaut's task is to monitor capsule instrumentation carefully enough to be in a position to perceive failures when they occur. In the Mercury capsule, the most dangerous malfunctions in terms of their consequences on the mission or in terms of the difficulty for the Astronaut to perceive them are set on warning systems which provide both a tone and a light cue on the enunciator panel. The purpose of the enunciator panel is to reduce the requirement for continuous vigilance. Following the perception of the failure, the Astronaut may take an immediate emergency action to insure that he and the vehicle are safe from further damage or deterioration due to the system malfunction.

Certain failures may tend to incapacitate the Astronaut, without his being aware of the malfunction. An example of this type of failure would be a reduction in the partial pressure oxygen in the cabin and suit circuits. This would be signaled by a tone and light on the enunciator panel. An appropriate emergency procedure in this case would be to close off the suit circuit from the cabin and go onto direct oxygen flow. This would guarantee sufficient breathing oxygen to the Astronaut. However, this procedure requires a high usage rate of oxygen. Consequently, if the problem which was producing the reduction in oxygen partial pressure could be isolated and the suit system purged, it might be possible to return to the normal environmental control system.

Thus, the emergency procedure attempts to block any further damage to the vehicle or to protect the Astronaut. It guarantees that the man and the vehicle are, for a period at least, in a safe condition. It allows time for the next step in the Astronaut reaction to a system malfunction. This third step is the isolation of the failure which has occurred. It is not necessary, of course, that the man determine the exact component which has failed. Instead, he is interested in what functions have been lost and to what extent or under what conditions he can return to the primary system. Once the failure has been isolated, it is possible to take an action which permits return to the primary system. This step may be termed "maintenance." The term maintenance is used in a very broad sense. This use is justified because in-flight system maintenance should not necessarily be limited to equipment that can be pulled out on the workbench and disassembled. In-flight maintenance may be more generally conceived as restoring malfunctioning primary systems, by whatever means this is accomplished.

Such corrective actions in the Mercury vehicle are, of course, extremely limited. This restriction has led to a question as to whether failure isolation is a significant requirement. There is, however, another strong requirement for failure isolation. Even if it is impossible to correct a failure and thus to return to the primary system, it may not necessarily compromise the mission itself. In some cases, sufficient redundancy is provided, so that secondary systems can carry out the full program of the Mercury mission. In other cases, failures which have relatively little effect, at the moment, may have great significance for the mission success at some later point in the planned operation. For this reason, it is important to isolate the failure as carefully as possible so that step five, the mission reevaluation, may be carried out. This involves determining the effect of the failure on the mission. In reevaluating the mission status, certain other factors come into play; the remaining quantities of various consumables; the present position of the capsule and predicted time to a normal landing point; and finally, the overall operational objectives. If, on the

basis of this analysis, a change in the flight program is required, then the Astronaut goes on to take the necessary steps to initiate early retrofire and reentry. In all these steps, he coordinates his activities with the Mercury range stations, where possible, receiving the benefit of the analysis and advice of systems specialists on the ground.

Sequence Monitoring

During the Mercury flight, a series of events take place which must be carefully programmed to occur in correct sequence and at the proper time. During the launch, the escape tower must be jettisoned when no longer needed; the capsule must separate from the booster. On return from orbit, the retrofire maneuver must be carried out, the retrorockets jettisoned, the autopilot properly programmed, parachutes and impact bag deployed. All of these events are controlled by automatic sequencing systems. To permit the man to back up this programming system, a set of display lights for each major event in the launch and reentry sequence has been placed on the left-hand section of the instrument panel. Associated with each light is the Astronaut's manual override. The basic concept of this light system is that a red light will come on in the event that the item is due but has failed to be activated by the automatic system whereas a green light will come on if the automatic system has functioned correctly. The intent of this arrangement is that the man should make a response in the presence of the red light and no response in the presence of the green light. Stated in these terms, the task seems to be a simple one. However, a deeper analysis of this aspect of the Astronaut's job indicates that such an assessment is misleading.

If the man is to carry out this task, he must substitute himself for the malfunctioning automatic programmer. In figure 5, the automatic and manual programming systems for deploying the main parachute are contrasted. The main "chute" telelight is illuminated from behind by two red and one green bulb. Let us look at the mechanism for lighting these bulbs. The sequence begins with twin 10,000-foot aneroids which send a signal to a 2-second time-delay unit and to the main chute deployment relay. A circuit through this 2-second time-delay unit will light the red lights on the main panel unless the signal that the chute is being deployed comes back within that time. The signal to the main chute relay permits a signal to go to fire the antenna fairing. Antenna-fairing separation is sensed by the antenna-fairing sensor which in turn sends a signal back to the 2-second time-delay circuit, blocking the lighting of the red lights. It also applies a voltage to the green light. The antenna fairing pulls the main chute with it.

It is interesting to note the effects of various malfunctions on the Astronaut's display. If the system failed at the 10,000-foot aneroids (labeled (a) in the diagram), then no signal would come from this unit and the light would not light either red or green and the chute would fail to deploy. In case (b), where the green bulb fails to light, the pilot would get the same indication, that is, no light; but the automatic system would perform correctly and deploy the chute. If the main chute deployment relay malfunctioned (case (c)), then the failure warning would work as intended, namely the red lights would light and the chute fail to deploy. If, however, the failure were in the antenna fairing sensor, a red light indication would be obtained but the chute would deploy. If the chute deployed, but streamed, as in malfunction (e), then a green light could come on, on the main panel, but failure of the main chute system would still occur. Thus, it is possible to get no light and have a failure; to get no light and have a proper function; to get a red light and have a failure; to get a red light and have a proper function; to get a green light and have a failure as well, of course, as the most probable event having a green light and proper function. Now, the probability of any one of the malfunctions involved here is very low, just as the probability of failure of the whole system itself is low. However, while the probability of malfunction of any given component is very low, because there are such a large number of units in the many systems which make up the Mercury capsule, a significant possibility of malfunction remains. It is the function of the man in this system to take over in the event of such malfunction and substitute himself for the automatic system. From the example outlined here, it can be seen that in the sequencing system, it is not possible to rely entirely on just the color of the sequenced light. The fact that instruments may sometimes be untrustworthy is certainly no novel finding for any one familiar with aircraft or even with the automobile. However, it is often possible to overlook the full performance requirements when describing the task only in terms of the external signal immediately available to the pilot.

In order then to carry out this sequencing function effectively, the pilot must be his own programmer. This is illustrated by the manual system outlined on the left-hand side of figure 5. This manual programming system can be analyzed as a three-step procedure for each item in the sequence. The first step is obtaining a cue as to when a given sequence item action should occur. In the present case, the altimeter indication of 10,000 feet provides a cue that the main chute should be deployed. The next step is to check the main chute telelight to see that the automatic system has functioned. He can then verify the indications given him in the telelight by checking the rate-of-descent indicator which should fall to 30 feet per second. If, on verification, he finds that the automatic system has failed to deploy the chute, he has the choice of using his own pilot control ring for

the main chute or if there is an indication that the chute was deployed but did not open properly, he could jettison that chute and deploy the reserve by using the pilot's ring on the reserve chute.

This schematic representation of the manual sequencing process is oversimplified, of course. The pilot has other cues than the rate-of-descent indicator with which to verify deployment of the main parachute. Most effective will be his own visual inspection of the chute, using the window or the periscope. It does serve, however, to emphasize the total process of pilot's activity at this time. He is attempting to get cues for the initiation of critical events by use of his flight instruments, such as the accelerometer, altimeter, rate-of-descent indicator and clock. He is checking his sequence panel for indications that the automatic programmer is working properly. Finally, he is verifying the action of the automatic system or his own manual override action by use of flight instruments, external vision, sound or acceleration cues.

Attitude Control

Since the launch is automatically programmed through the Atlas or Redstone boosters, the pilot has no attitude control problem while attached to the missile. When the capsule is in orbit and during the reentry, attitude may be controlled by either the autopilot or the Astronaut. In controlling the attitude of the Mercury capsule, the Astronaut may encounter four basic types of problems: controlling attitude in orbit; controlling attitude during retrofire; rate damping during reentry; and recovery from tumbling maneuvers. Controlling attitude in orbit is a relatively simple problem, as long as high accuracies are not required. Unlike aircraft operating within the atmosphere, the attitude of the vehicle itself does not influence flight path in orbit, as long as secondary power is not being applied. In most cases, rapid actions will not be required. Slow movements to get into position will be satisfactory.

The second type of problem faced in Mercury attitude control is maintenance of attitude during retrofire. This is the most difficult of the attitude control problems. During the retrofire maneuver, the Astronaut must hold the position of the capsule within certain tolerances in order to get the full value of retrofire. The retro-rockets will be aligned so that the force vector will pass through the center of gravity of the vehicle. However, due to the use of consumables and other factors, the retrorockets may not be perfectly aligned at the time of retrofire. In this case, they will produce torques about the major axes of the vehicle, particularly in the yaw and pitch planes. These torques develop rapid rates of motion about the axes which must be controlled by the Astronaut.

A third attitude control problem is reentry rate damping. The Mercury vehicle is statically stable on reentry, at all Mach numbers. However, during reentry, the capsule may experience oscillation about the reentry attitude. Large oscillations may produce excessive heating on the vehicle afterbody. The Astronaut, in the event of the failure of the automatic system, must damp these oscillations. In applying damping, he concerns himself only with vehicle rates. This is in contrast to the information required in a lifting reentry vehicle, where the Astronaut would be controlling the vehicle attitude on reentry in order to make use of lift to reduce acceleration and heating.

A final problem is recovery from a tumbling maneuver. It is possible that on separation from the booster, the capsule may receive a torque which causes it to tumble. This may cause gyro gimbal lock or tumbling, which will result in the attitude indications being inaccurate. The rate indicators, however, will not be affected by tumbling and will give an accurate indication of the movement about the three axes of the vehicle. In this situation, the Astronaut brings his rate to zero and then can manually erect his gyros.

To perform these tasks the Astronaut has available to him, three manual attitude-control systems, in addition to the basic automatic control system; a "fly-by-wire" system, which works through the autopilot; a direct manual system, which works through mechanical linkages to the manual control fuel valves; and a rate-command system which also uses the manual fuel system, but which has a logic circuit to provide rate damping. The Astronaut also has three basic display systems: his instruments, which include a rate and attitude display; a periscope, which permits ground viewing and determination of the earth vertical; and a small window, which provides a view of the earth's horizon.

Experience with this control system has uncovered a number of interesting problems for the Mercury Astronaut. In using the reaction controls which are acceleration controls in a frictionless environment, the importance of a rate display is greatly increased. Thus, on the Mercury panel, the three rate needles occupy the central position in the instrument group. During the most difficult attitude control task, retrofire, the rate indicators are the primary reference for the pilot. He cross-checks against attitude indicators, making corrections when these show variation from the retroattitude. However, most of the control actions are taken in response to changes on the rate indicators, which give him the most immediate indication of the effects of retro-rocket fire. During the reentry rate-damping task, the attitude indicators are inoperative, and he has only rate information. For the least demanding of three tasks, attitude orientation in orbit, the attitude indicators become the primary instrument, particularly where the maneuver is carried out in only one axis, as is usually possible. However, increased fineness of control is possible, through reference, to the rate indicators. As described previously, the rate indicators also play an essential role in the recovery from a tumbling maneuver.

The attitude control problem is affected by a number of sources of coupling. It is difficult to operate the three-dimensional hand controller without some cross coupling between axes. Further, the manual reaction jets are slightly out of line, which produces a small amount of coupling between axes. Most important is the apparent coupling on the instrument display when the vehicle is in an unusual attitude. Since the attitude gyros are fixed in reference to the earth, if the vehicle pitches up 90° , the yaw and roll axes will appear to be interchanged on the attitude indicators.

External attitude reference also presents some special problems. Through the window, the pilot will get a typical wind screen view of the earth, which should provide good roll and pitch reference, as long as the horizon can be discriminated. It is possible that on the dark side of the earth, in the absence of the moon, the horizon will be difficult to see. Yaw reference will be a more difficult problem than on aircraft, because the rapid rate with which the terrain moves below the vehicle does not permit the use of a landmark as a heading reference. On the other hand, the drift rate as seen from the vehicle is not rapid enough to provide a good yaw reference. Moreover, the use of drift is complicated by the lack of patterning when over water, clouds, or the dark side of the earth. In addition, small residual pitch and roll motions can easily be confused with drift. Probably the most valuable yaw reference will be the stars as seen through the window, since they will remain fixed in yaw relative to the capsule's orbit. The primary question with regard to use of stars for reference will be their visibility, particularly on the daylight side where strong light from the sun and reflected light from the earth may interfere with viewing out the window. Like the window, the periscope provides relatively good reference for pitch and roll control. But determination of yaw must be based on measured drift. Since much of the orbit will be over clouds or water, without patterned objects which can be used to determine drift, yaw reference through the periscope may be difficult. Also, it should be noted that since the periscope will reduce the image of the earth by a factor of 9, roll and pitch rates as perceived through the periscope will be $1/9$ of those indicated by the instruments or seen through the window. Another problem that arises in adapting to the use of the periscope is a slight initial confusion between yaw and roll. Being used to wind screen view of the earth, the Astronaut tends to interpret circular motions as being due to roll. However, since the periscope looks normal to, rather than parallel with, the earth's surface, rotational motions are actually yaw rather than roll. This has been an initial source of confusion in using the periscope on early training efforts.

Navigation

The Astronaut should have a good knowledge of his position at all times. Two specific navigational requirements for the Astronaut can be noted. The first and most essential of these is for impact-point prediction and control. The vehicle in orbit is moving at approximately 5 miles per second. The normal recovery zones, at the end of each orbit, are approximately 150 miles in length. Since the nominal impact point will be in the center of these zones, an error of ± 75 miles will place the capsule outside the primary recovery zone. At 5 miles per second, the 75 miles is equal to a 15-second error. The second requirement for Astronaut knowledge of the capsule position is to facilitate communication with ground stations and observation of predetermined check points. Contact with monitor stations will vary between 2 to 5 minutes. For the shorter station passes, the Astronaut will be required to be alert and ready to communicate. Since the possible contact is so short, an error by the Astronaut in estimating his estimated time of arrival (ETA) at the station could result in a failure to contact that station. In addition, terrain features of special interest and ground check points will be designated in advance. Failure to predict the ETA correctly over these areas might result in his missing valuable observations.

The position of the capsule at any time can be calculated from the nominal trajectories. The Astronaut is provided with a map on which elapsed time since launch is marked along the orbit tracks in minute intervals, permitting the Astronaut to determine his estimated position, by referring to the elapsed time clock. By interpolation, the Astronaut may achieve an accuracy of approximately ± 15 seconds. If the capsule achieves the nominal trajectory, the ETA over any given point should be calculable within 15 seconds. Given this trajectory and an accurate clock, the Astronaut should be able to time the retrofire accurately enough to reenter within one of the primary recovery areas. In actual operations, the Astronaut would not attempt to read the retrotime off his map, but would carry with him the retrotimes for each of the primary recovery areas. If the capsule was on the nominal trajectory, the exact retrotime could be set into the clock. The primary navigational problems arise, then, when the capsule trajectory deviates from the nominal trajectory. In this case, the Astronaut must first determine the extent to which the trajectory is deviating from the nominal trajectory and then adjust retrotime accordingly.

Three methods are available to the Astronaut for updating the nominal trajectory. The primary and probably the most accurate method, assuming proper function of the complex range system, would be the ground computed position. This system depends upon radar trajectory data from the launch site and from other radar sites around the earth,

which are transmitted to a central computer facility. On the basis of this information, the computer will provide an accurate retrotime in terms of elapsed time. This information must be transmitted over the range communications network and then to the Astronaut. Should all components of this system function correctly, it should provide a high level of accuracy in computing the specific retrotime. It is dependent, however, upon a rather complex system of communications between the capsule and the ground and between stations on the ground.

A second method for the Astronaut to update the nominal trajectory is by use of ground reference. Through the capsule periscope, the passage of ground check points directly below the capsule can be timed. From these ground fixes, the nominal orbital data may be modified. The use of ground reference depends upon (1) good ground visibility, (2) proper alinement in attitude, and (3) an accurate clock. These factors are discussed in more detail below.

The third method of correcting the nominal trajectory is through celestial reference. By use of scribe lines on the capsule window, capsule position can be determined by reference to the celestial sphere. This method depends upon (1) visibility of the constellations of the Zodiac, (2) proper attitude orientation, and (3) an accurate clock.

Of the three factors affecting the Astronaut's determination of position from external fixes, the accuracy of the capsule clock should provide the least error. The clock is being fully qualified for the conditions expected during the flight and over the launch, and a short period of time should not cumulate significant errors. In addition, it is completely mechanical. Therefore, even a loss of electrical power in the vehicle would not affect the clock. The problems of external visibility from the capsule have been discussed in some detail by Edward R. Jones of McDonnell Aircraft Corporation in a paper presented before the Aerospace Medical Association in May, 1960. Factors affecting ground visibility will be the amount of cloud coverage (perhaps as high as 50 percent or more) and the light available. On the daylight side of the earth, there should be plenty of illumination in which to see ground reference points. However, on the dark side, it may be so dark that the ground check points cannot be distinguished. In addition, the large water areas of the Pacific and Indian Oceans may not provide recognizable check points. Ground visibility status will be affected by external and internal lighting conditions. On the light side of the earth, the sun and the reflected light from the earth's surface may provide so much contrast that the stars become invisible. Further, the requirement for structural integrity and for the reduction of reflections due to internal light on the capsule window have resulted in a window design which greatly reduces the amount of light transmitted with the result that the

visibility of the stars will be greatly decreased. In addition, unless dark adaptation can be maintained on the light side of the earth and the capsule lighting dimmed, the visibility of stars, even on the night side, may be somewhat limited.

The third problem, attitude control, greatly favors use of ground check points as compared to the use of the celestial sphere as a reference. The autopilot will maintain the capsule attitude within $\pm 3^\circ$ about the three axes of the vehicle. The effect of such errors is smaller in the case of ground check points than in the case of star reference. An error of 1° in maintaining the earth vertical would result in less than a 2-mile error at an altitude of 100 miles. On the other hand, the same amount of error in reference to a star amounts to approximately 60 miles at the equator. Since the capsule is traveling at approximately 5 miles per second, the error due to vehicle attitude is within the reaction time error of the Astronaut, since it is unlikely that he can time the arrival at a check point to an accuracy greater than 1 second.

Communications

Through the medium of communications, the complex systems which make up the total Mercury mission must be integrated. Critical units of the launch range and recovery systems are the blockhouse, booster-guidance systems, the Mercury range which consists of a central control station, 13 range stations, and a computer center, and finally, the recovery units. The Astronaut communicates with the blockhouse and central control prior to launch with the 14 range stations during the flight and with the recovery forces in his area following the flight. The range sites are situated around the world in such a position that the Astronaut will be able to communicate with one of these stations approximately 50 percent of the time he is in orbit. The longest period between stations is 20 minutes.

Through this range network, the Astronaut receives 7 basic types of information. During the launch, he receives information on the booster and the capsule trajectory. This communication is essential since the Astronaut has no immediate information on the booster status. The ground informs the Astronaut on the progress of powered flight and informs him immediately of any problems with booster or ground guidance. The second type of information from the ground is for the purpose of providing sequencing cues. During the launch and reentry, the Astronaut can be given an indication when certain important events such as tower jettisoning, separation, and chute deployment should occur. These data can be based on ground time information or ground trajectory information.

A third function of the ground system is to provide the Astronaut with a backup in the area of systems monitoring. Generally, the Astronaut has more complete information on the function of the vehicle system than the ground personnel; however, it is possible that he may fail to note an indication of a malfunction. Moreover, in some cases, the ground monitor has information not available to the Astronaut. In these cases, the flight controller is able to feed additional data to the Astronaut for evaluation. Finally, based on the Astronaut's description of events in the capsule, together with telemetered data, engineers on the ground may be able to advise him as to the probable malfunction. Fourth, the Astronaut receives medical information on his physiological status. On the ground, the Flight Surgeon has available to him telemetered heart rate, respiration rate, and temperature. These data, of course, are not available to the Astronaut. The Astronaut's subjective feelings may not be reliable, particularly under the conditions of the flight; therefore, the medical monitors are in a position to alert the Astronaut, should there be an indication that a medical problem is developing.

A fifth function of the ground personnel is to maintain graphs of the major items of consumables aboard the capsule, such as fuel, cooling water, oxygen, and so forth. These plots are based on telemetered data, together with confirmed reports from the Astronaut, and can be evaluated by ground personnel to determine that the rate of use of these items is as programmed. Sixth, the ground services provide information on the weather, the recovery ships, and the status of the range. The weather information is critical, not only because sudden changes in weather status might make reentry in one of the planned areas undesirable, but in addition, because the weather will control the observations the Astronaut can make and his ability to make ground checks for position. The status of recovery ships may also influence his choice of reentry point, while the status of the range stations may determine where he will be able to communicate. Finally, (seven), the communications to the pilot serve the purpose of updating his time and navigation information. The pilot will begin navigation, based on the nominal trajectory. Based on the actual insertion parameters, range personnel will be able to inform him of deviations from the nominal trajectory, which should permit the Astronaut to determine his position more precisely.

In addition to these items of information, which are sent to the Astronaut, the Astronaut sends to the ground data in four areas. First are the reports on such items as his own status, his subjective feelings, and his apparent well being. Second is information on the capsule systems status as he sees them. This area includes information on such things as what mode of control he is using, whether he is on primary or secondary systems, and similar data. In addition, he will

report the instrument readings on critical parameters such as fuel and oxygen quantities, in order to verify and cross-check against ground telemetry data. Thirdly, he reports the mission status as he understands it. He reports his position, based on his own navigational fixes, his retrotime, the status of his planned program of activities, and so forth. Finally, he reports on the observations he is making, both of himself and his own performance, the vehicle and its performance, and of the external environment.

Three critical decisions can be made by using communications. First, the Astronaut, in concert with ground information and ground advice, may determine what corrective actions are to be taken in a given situation. Since the Astronaut has the most complete information on the vehicle systems, most corrective action will result directly from his own knowledge of the vehicle and the information directly available to him. However, in some cases, information and advice from the ground may play an important role in taking corrective action, particularly where medical information which is not available to him plays a role in determining the need for action. A second critical decision that is made through the communications is the "Go-No Go" decision just prior to the insertion of the capsule in orbit. If an abort is to be made because of the capsule status, it must be made prior to burnout of the sustainer stage, in order to return the capsule in the Atlantic Ocean. Thus, a positive decision is required just prior to burnout, that the capsule and the Astronaut are in condition to be inserted in orbit. This decision is made by the ground flight controllers and the Astronaut. A final decision area is the decision to terminate the mission. The mission will normally terminate at the end of three orbits. However, if malfunctions develop or if range conditions do not permit recovery in the planned third orbit area, an earlier recovery may be necessary. The decision of where and when to terminate the mission is a critical one, requiring precise information on the required time for retrofire. The decision to terminate the mission will require a maximum coordination between the Astronaut and the range.

In-flight Research

Research and evaluation programs which involve the Astronaut can be divided into four general categories. First, the Astronaut will be required to make evaluations of the vehicle function and performance. This is the traditional job of the test pilot. He reports to the ground indications of the vehicle's performance, particularly in areas where telemetry or onboard record systems are not providing measurement. He also investigates maneuvers which are not provided for in the automatic programming of the system, thereby evaluating the system under unusual conditions which can more fully test its capabilities.

A second role of the Astronaut is to observe the space environment in which he travels, including the heavenly bodies and the earth below him. In this, he attempts to bring back information which will be valuable to earthbound scientists in such areas as astronomy, meteorology, geophysics, and so forth. Thirdly, by submitting to physical examination before and after the mission, by reporting on any medical symptoms which he may experience, and by allowing medical personnel to draw blood and urine samples, he provides medical data for analysis of the human physiological responses to the space environment. Finally, by performing his in-flight activities, such as monitoring the vehicle systems, making voice reports, controlling vehicle attitudes and in certain cases, doing special performance tasks, he provides data on which his performance capability can be evaluated.

Physical Stress Management

During the flight, the Astronaut will be exposed to acceleration, reduced pressure, heat, vibration, noise, and possibly such abnormal conditions as tumbling and high levels of carbon dioxide. If he is to perform the tasks described previously, he must be able to react appropriately to these stresses. He must be sensitive to these conditions to the extent that they provide cues to system function during the mission. At the same time, he must not allow them to divert his attention from his flight task. In some cases, there are specific skills in the management of these stresses which can be learned and practiced. For example, to minimize the grey out and the sub-sternal pain due to the transverse g , the Astronaut can make use of a straining technique. This technique can be learned by centrifuge training and must be consciously exercised. In addition, through the somewhat subtler changes produced through repeated exposure to the physical conditions of the flight, an adaptation to these stresses can be achieved which will maximize his resistance to performance decrements as a result of exposure to them. He must learn to regulate his behavior and activity level so that he does not overly fatigue himself when in the full pressure suit. During the reentry and the postlanding heat pulse, he should remain as quiet as possible so as not to generate extra heat to complicate an already difficult cooling problem. Thus, the Astronaut must be more aware of his own function and its interaction with the environmental control system which supports him. He must develop the skills and knowledge which are required to work effectively within this more limited environment without taxing himself or overloading the environmental system.

Ground Tasks Associated With Launch and Recovery

The Astronaut has an important role in the preparation of the vehicle for the flight. The Mercury capsule will arrive at the launch site at 6 to 8 weeks prior to the launch date. During this period, the capsule will be mated to the booster, and checks of the capsule systems and the compatibility between capsule and booster systems will be made. Many of these checks will require that controls within the vehicle be operated. It is desirable, both for training and for proper equipment checkout that the Astronaut take part in these activities. During the countdown, he will observe and aid in the preparation of the vehicle. He will communicate with the blockhouse and participate in that part of the countdown associated with the checkout of the vehicle and Astronaut system.

After the Astronaut returns to earth and lands in the water, he must wait for pickup for a period from 30 minutes to several hours, depending on the accuracy with which he has been able to return to a planned recovery area. In the unlikely event that he should have to abort and return outside a planned area, the delay in pickup might be even more prolonged. The Astronaut, therefore, must be able to survive in the water, either in the vehicle itself, or if that should prove to be untenable, in his life raft. In the unlikely event that he comes down on land, he must be able to survive in tropical or desert areas for prolonged periods and to aid in his recovery by using various signaling devices.

Nonflight Tasks

It should be noted that there is a second major category of Astronaut activities which has not been covered in this discussion; these are the nonflight tasks. The glamorous part of the Astronaut's job, the function which catches the most attention, is, of course, the flight itself. While this is the focal point of the Astronaut's activities, it is generally not recognized that the Astronauts have duties and functions outside of preparing themselves for the flight. One of these assignments is to make contributions to the design of the Mercury vehicle, crew space and Astronaut personal equipment. Shortly after the Astronauts reported to Project Mercury, they were given an opportunity to go to McDonnell Aircraft Corporation, view the capsule mock-up and make suggestions for the crew-space layout, instrumentation, and manual-control system. These early contributions resulted in a number of significant improvements in these areas. In addition to design recommendations, the Astronauts have, on occasion, participated in design studies. The best procedures for the protection of the man against acceleration, the design of the hand controllers,

and other factors of this type require design studies to which the Astronaut can contribute by being a subject under test.

In addition to his contribution to systems design, the Astronaut can aid in system development by being available for fitting and integration with the vehicle components. For the Mercury vehicle, a special couch must be molded for each man. The mounting of the couch within the capsule varies for each man in order to give him an optimal viewing distance from the instrument panel. In addition, pressure suits must be individually fitted. These special fittings require considerable lead time in themselves. Since the number of individuals who will have an opportunity to make space flights in the near future will be very limited, it will be both feasible and desirable to tailor the crew space to the individual as much as possible.

As hardware comes off the production line, a test program must be initiated to qualify the equipment. For adequate evaluation of manual systems, a human operator is often required. While these evaluations can and in certain cases should be made by using engineers or technicians, it is desirable to make at least some of them with the Astronauts themselves in order to take advantage of their special knowledge of flight problems, and where possible, to meet their specific requirements. The Astronauts also aid in the Mercury program by contributing to the development of operational procedures for the vehicle, the launching site, and the range. While they came to Mercury with little practical experience with missile technology, all have had extensive operational experience with aircraft. Much of this knowledge can be applied to Mercury operational problems.

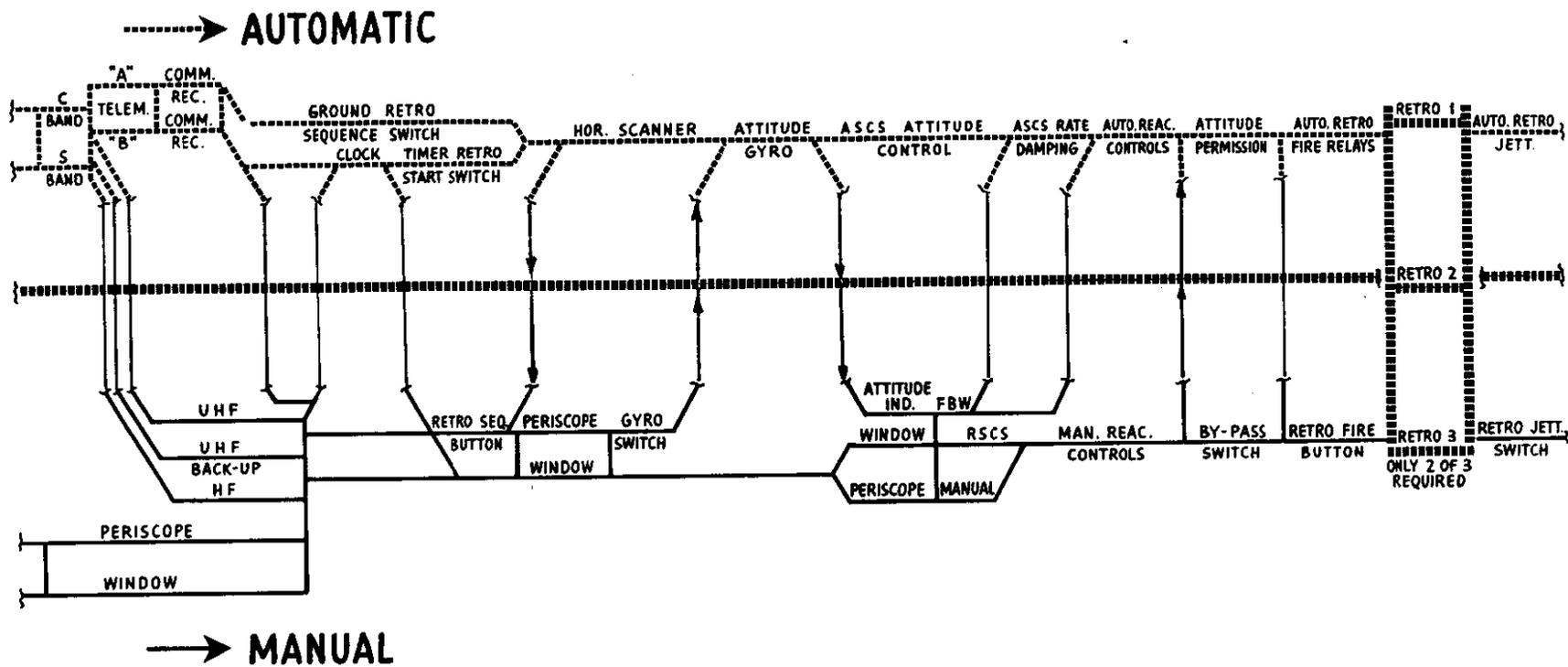
In addition to these engineering tasks, the Astronauts make an important contribution in the dissemination of information to the public. It is a truism that people empathize with other people better than they do with machines. The public's attention tends to be focused on the Astronauts because they can better understand his feelings and reactions than the technical aspects of the hardware. Thus, while an attempt is made by NASA to minimize the demands on the Astronauts in this area, they play an important role in interpreting Project Mercury to the public.

CONCLUSIONS

In conclusion, some of the major principles growing out of experience with the Mercury Astronaut's task may be reemphasized. This experience suggests that the most unique feature of space vehicles will be the requirement that they operate continuously for relatively

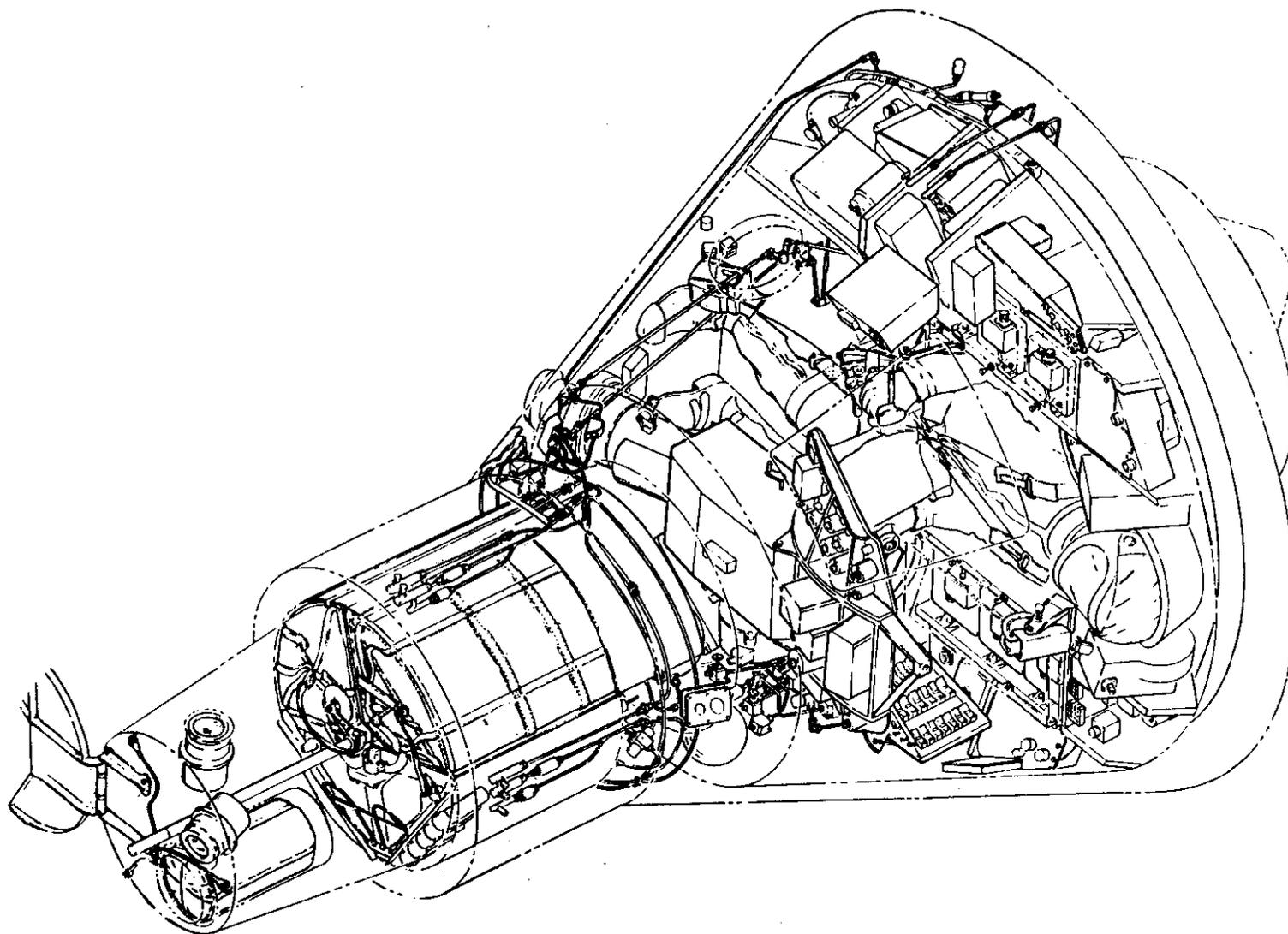
extended periods of time without access to ground maintenance facilities. Not only must they function for extended periods of time without extensive maintenance to accomplish their mission, but in the face of a serious malfunction, they must still have backup systems which can operate successfully for somewhat shorter but still lengthy periods in order to safely return the man to the surface of the earth. Because of the limitations in the present state-of-the-art of engineering, insuring this type of reliability is difficult, perhaps impossible, without man. The Astronaut can make his greatest contribution by detecting malfunctions and taking corrective actions to overcome them. Thus, the vehicle operator must take on much of the maintenance function that has formerly been delegated to ground crews. It appears likely that for long-term flights, this will become a more critical and difficult area for the vehicle operator than the more traditional tasks, such as attitude control, power management, and communications.

A corollary of the role of the Astronaut in increasing reliability is that he will often have to make use of less than optimal controls. Man's efficiency in controlling attitude as an example, can often be improved by "rate aiding" or "quickenings" or by power boosting the controls, and so forth. However, each of these auxiliary systems is dependent upon power and electrical or mechanical components which can malfunction. To the extent that man is dependent upon complex systems in order to make his inputs, his total contribution to reliability will be reduced by the unreliability of these components. In the past, when the operator could be supported by a large ground maintenance facility, it was often desirable to maximize his performance for the critical moments of flight at the cost of greatly increasing maintenance complexity. For space flight, where the operator must also do the maintenance, the trade-off may well be in favor of using simpler systems which require less maintenance and are more reliable, even at the cost of somewhat reduced proficiency in task performance.



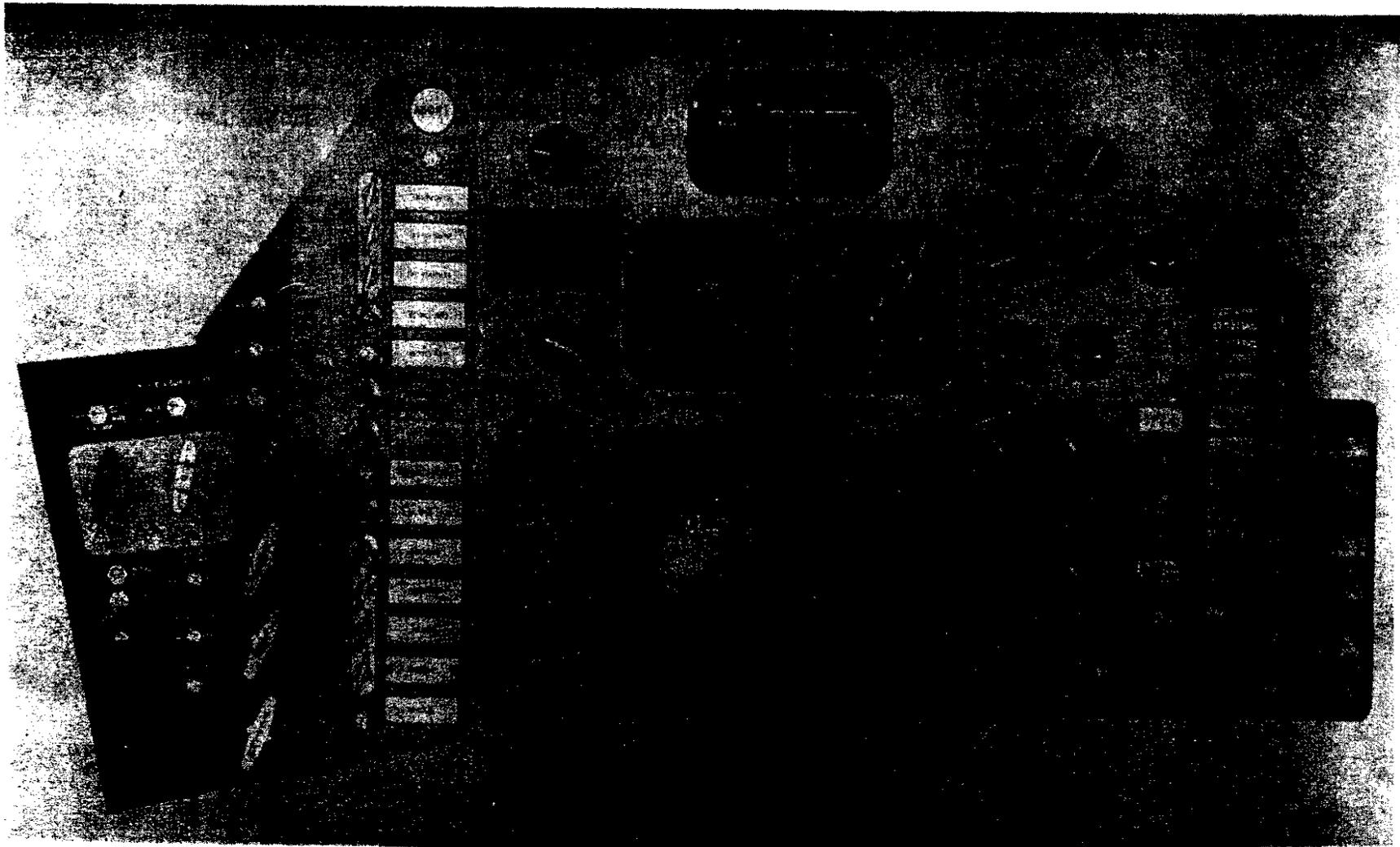
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Figure 1.- Retrograde maneuver, automatic and manual operation.

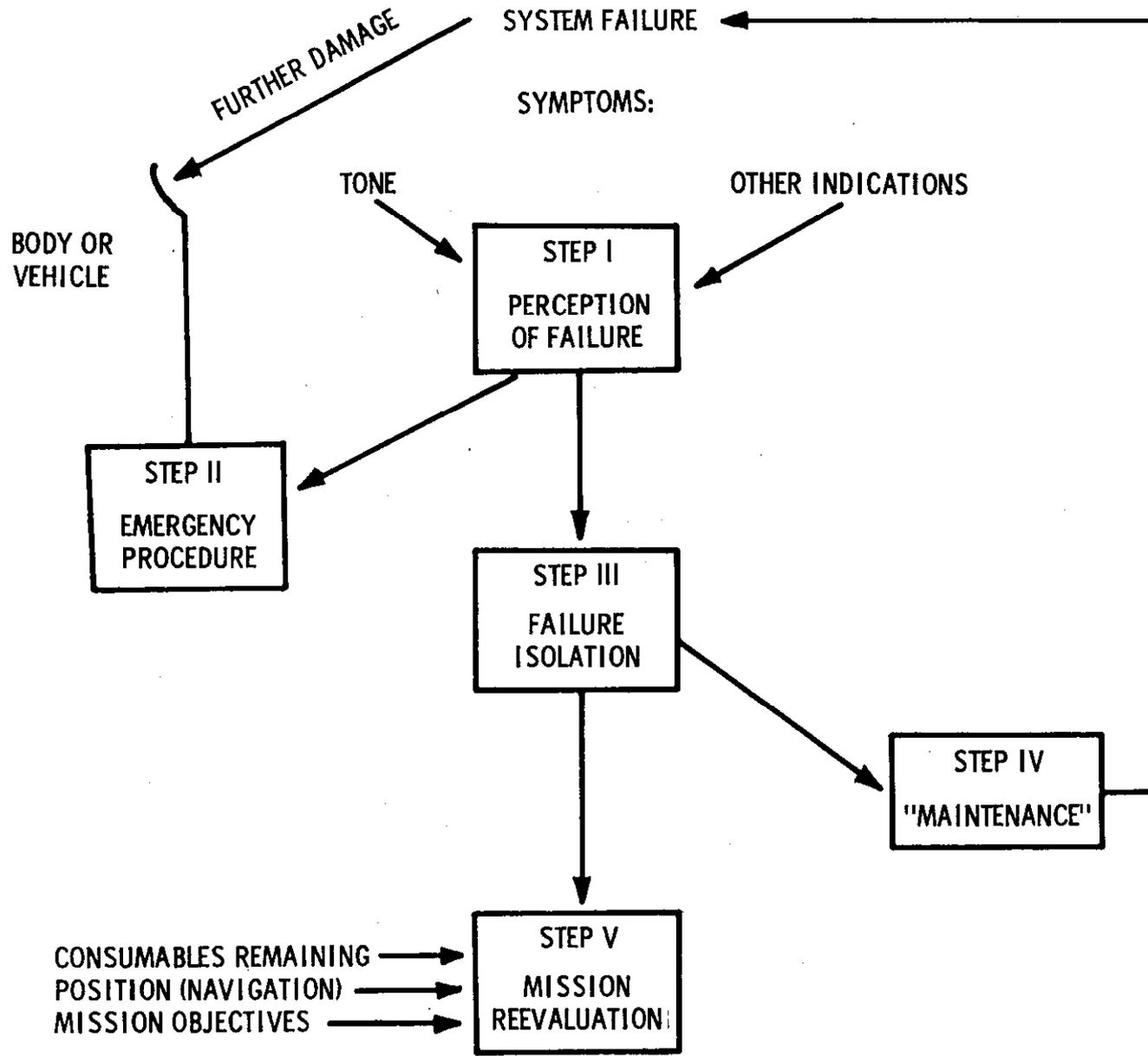


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Figure 2.- Capsule internal arrangement.

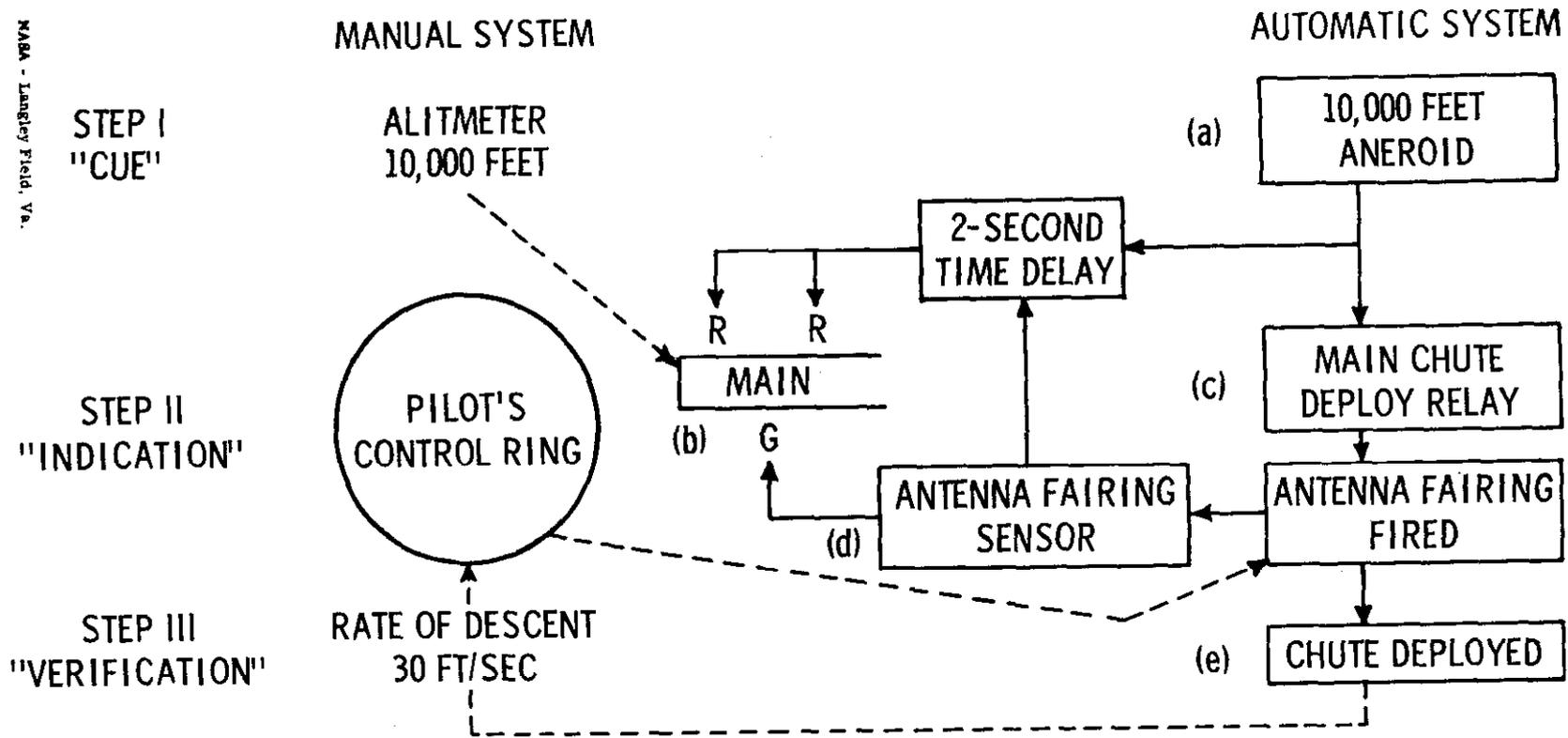


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Figure 3.- Pilot's panel.



NASA

Figure 4.- Schematic analysis of systems management.



ILLUSTRATIVE FAILURES

- (a) NO LIGHT - FAILURE
- (b) NO LIGHT - PROPER FUNCTION
- (c) RED LIGHT - FAILURE
- (d) RED LIGHT - PROPER FUNCTION
- (e) GREEN LIGHT - FAILURE

NASA

Figure 5.- Simplified diagram of sequencing system.